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Physics 230

Exam 1

Instructions: This exam contains 5 multiple choice questions worth 4 points each and 4 problems worth 20 points each. Do not refer to any book or notes during the exam. The time limit for this test is 50 minutes.

+84/100

Section I - Circle the letter that corresponds to the correct answer.

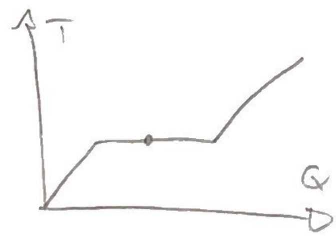
1. Water flows through a pipe having a varying width. More water flows per second through the wide section than through the narrow section because there is more room for it to flow.

Flow rate$_{in}$ = Flow rate$_{out}$

   a) True
   b) False

2. When a solid melts,

   a) the temperature of the substance increases.
   b) the temperature of the substance decreases.
   c) heat energy leaves the substance.
   d) heat energy enters the substance.



Add heat to change phase

3. When a fixed amount of ideal gas goes through an isobaric expansion,

$PV = nRT$

   a) its internal (thermal) energy does not change.
   b) the gas does no work.
   c) no heat enters or leaves the gas.
   d) its temperature must increase.
   e) its pressure must increase.

$P =$

$P = \frac{nRT}{V}$

4. A container is filled with a mixture of helium and oxygen gases. A thermometer in the container reads 22°C. Which gas molecules have the greater average speed?

   a) It is the same for both of the gases because the temperatures are the same.
   b) The oxygen molecules do because they are diatomic.
   c) The oxygen molecules do because they are more massive.
   d) The helium molecules do because they are less massive.
   e) The helium molecules do because they are monatomic.

$V_{rms} = \sqrt{\frac{3 K_B T}{m}}$

5. The average molecular kinetic energy of a gas can be determined by knowing

   a) only the number of molecules in the gas.
   b) only the volume of the gas.
   c) only the pressure of the gas.
   d) only the temperature of the gas.
   e) All of the above quantities must be known to determine the average molecular kinetic energy.

$E_{AVG} = \frac{3}{2} K_B T$

+16/20

Section II - For credit, show all work!

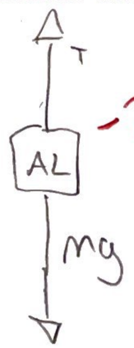
1. A block of aluminum, with a volume of 110 cm^3 and a density of 2,700 kg/m^3, is suspended by a string and completely submerged in ethyl alcohol. Ethyl alcohol has a density of 790 kg/m^3.

12/20

   a) Construct a *free-body diagram* showing all forces acting on the submerged block.

   b) Calculate the tension in the string.

a.)



-2

T is same as buoyancy in this scenario

NO FORCE of GRAVITY?

$T = F_B$

-2

b.) $V = 110 cm^3$ $\quad 110 cm^3 \cdot \frac{(0.01m)^3}{(1cm)^3} = 1.1 \times 10^{-4} m^3$

$V = 1.1 \times 10^{-4} m^3$

Since $\Sigma F_y = 0 \therefore F_B = mg$

$F_B = \rho_F V_F g$ ✓

$m = \rho V$

$\rho = m/V \therefore m = \rho_F V_F$

$m = 2700 kg/m^3 (1.1 \times 10^{-4} m^3)$

$m = 0.297 kg$

$mg = (0.297 kg)(9.8 m/s^2)$

$mg = 2.91 N$

$T = 2.9 n$ ✗ -4

Ar = monatomic

Two sig figs

2. 0.10 mol of argon, which is a monatomic gas, is admitted to an evacuated 55 cm^3 container at 23°C. The gas then undergoes an isothermal expansion to a volume of 220 cm^3.

+20/20

a) What is the final pressure of the gas?

b) Draw a pV diagram showing this process. This diagram needs to include axes and labels and an arrow indicating the direction traversed between the initial and final points on the pV curve.

$PV = nRT$

$cm^3 \to m^3$ ($\times 10^{-6}$)

$220\ cm^3 \ \frac{(0.01m)^3}{1cm}$

$220 cm^3 = 2.2\times10^{-4} m^3$

$55 \cdot \frac{(0.01m)^3}{(cm^3)} = 5.5\times10^{-5} m^3$

a.) $V_0 = 5.5\times10^{-5} m^3$ $\quad V_1 = 2.2\times10^{-4} m^3$

$T_0 = 296\ K$ $\quad T_1 = 296\ K$

$P_0 = 4.5\times10^6\ Pa$ $\quad P_1 =$

$n = 0.10\ mol$

$$P_0 = \frac{nRT_0}{V_0} = \frac{(0.1 mol)(8.315/mol k)(296k)}{(5.5\times10^{-5} m^3)}$$

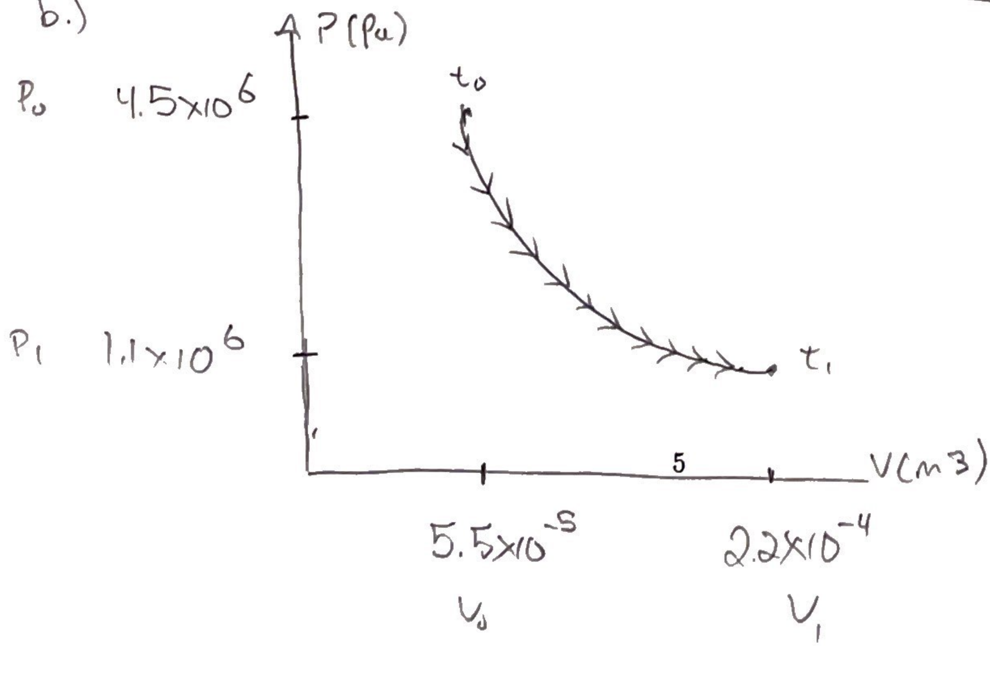
[P] $P_0 = 4.47\times10^6\ Pa$

$$P_1 = \frac{nRT_1}{V_1} = \frac{(0.1mol)(8.31 J/mol k)(296K)}{(2.2\times10^{-4} m^3)}$$

$P_1 = 1.11\times10^6\ Pa$

$P_1 = 1.1\times10^6\ Pa$

b.)



+20/20

3. A monatomic gas follows the process $1 \to 2 \to 3$, as shown in the figure below.

   a) Calculate the temperature of the gas at state 2.

   b) Calculate the heat, Q, work done on the gas, W, and the thermal energy change, ΔE_{th}, for the gas as it goes through *both* of the aforementioned processes.

$P_1 = 3atm \quad P_2 = 3atm$

$V_1 = 1.0\times10^{-4} m^3 \quad V_2 = 3.0\times10^{-4} m^3$

$t_1 = 373K \quad t_2 =$

$PV = nRT$

$100 \times (0.01m)^3 = 1.0\times10^{-4} m^3$

$n = \frac{PV}{RT} = \frac{(3)(1.01\times10^5 Pa)(1.0\times10^{-4} m^3)(1cm)^3}{(8.31 J/molK)(373K)}$

$n = 0.009$ mol ≈ 0.01 mol

1 sig fig?

$300\times(0.01m)^3 / (1cm)^3 = 3.0\times10^{-4} m^3$

a.) $T_2 = \frac{P_2 V_2}{nR} = \frac{(3\times1.01\times10^5 Pa)(3.0\times10^{-4} m^3)}{(0.01 mol)(8.31 J/molK)}$

$P = 3.03\times10^5$

$T_2 = 1093.8$ K $\quad T_2 = 1100$ K

b.) 1→2 Isobaric ∴ $W = -P\Delta V$

$P = 3.03\times10^5 Pa$

$\Delta V = 2.0\times10^{-4} m^3$

$W_{12} = -60.6 J$

$\Delta E_{th} = W + Q$

$Q = \Delta E_{th} - W$

$= (90.6) - (-60.6)$

$Q = 151 J$

$\Delta E_{th,12} = nc_v\Delta T$

$n = 0.01 mol$

$\Delta T = 727K$

$c_v = \frac{3}{2}R$ — mono

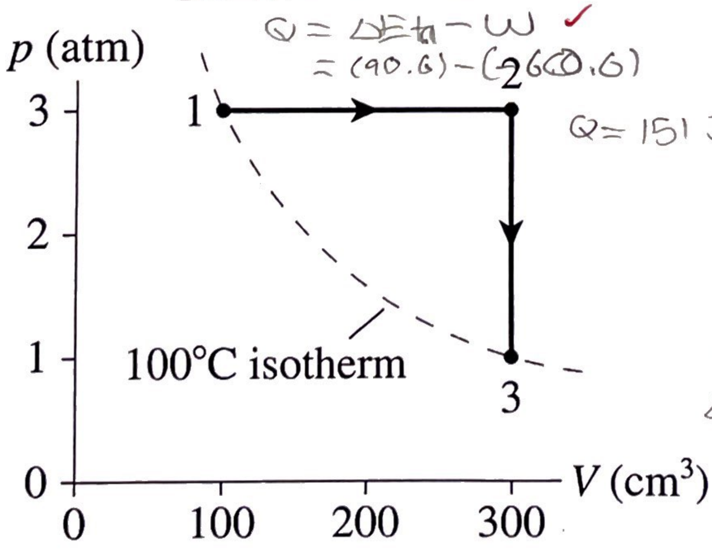
$\Delta E_{th,12} = 90.6$

For 1→2

$\Delta E_{th} = 91 J$

$W = -61 J$

$Q = 151 J$



2→3 Isochoric

∴ $W = 0$

$\Delta E_{th} = Q$

$\Delta E_{th} = \frac{3}{2}nR(373 - 1100K)$

$\Delta E_{th} = -90.6 J$

For 2→3

$\Delta E_t = -91 J$

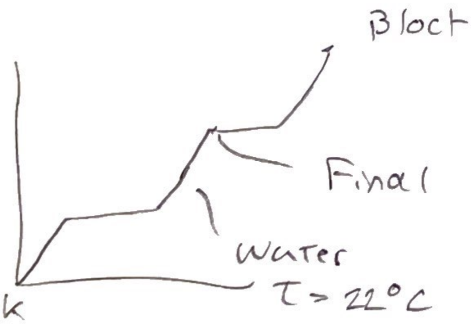
$Q = -91 J$

+16/20

4. A 512 g block of iron is removed from a 790.°C furnace and immediately dropped into 210. mL of 22.0°C water. The specific heats of water and iron are 4,190 J/kg·K and 449 J/kg·K, respectively. The latent heat of fusion for water is 3.33×10^5 J/kg and the latent heat of vaporization for water is 22.6×10^5 J/kg. When the iron and the water finally reach thermal equilibrium, the water's temperature is 100.°C.

   a) For this calorimetry problem, construct the main governing equation symbolically in terms of the given constants and desired unknown(s).

   b) What fraction of the water boiled away?



a.) $Q_P + Q_{\Delta T} = 0$

$M_b = 0.512$ Kg $\quad m_w = $

$T_{b_1} = 1063$ K $\quad T_{w_1} = 295$ K $\quad T_f = 373$ K

$Q_P = m_w L_v \quad Q_{\Delta T} = m_b c_b \Delta T_b + m_w c_w \Delta T_w$

$Q_{net} = 0$

prefactor -1

$$Q = m_w L_v + m_b c_b \Delta T_b + m_w c_w \Delta T_w = 0$$

b.) m_w boiled away? $\quad \rho = \frac{M}{V} \quad m = \rho V$

$1000 L = m^3$

$1 mL = 1000 L$

$m_w L_v + m_w c_w \Delta T_w = -m_b c_b \Delta T_b$

$m_w (L_v + c_w \Delta T_w) = -m_b c_b \Delta T_b$

$m =$

$$m_w = \frac{-m_b c_b \Delta T_b}{L_v + c_w \Delta T_w}$$

$m_w = 0.061$ kg

$210 mL \cdot \frac{1 L}{1000 mL}$

$0.21 L = \frac{(m^3)}{1000 L}$

$V = 2.1 \times 10^{-4} m^3$

$\Delta T_w = 78$ K

$\Delta T_b = -690$ K

$c_b = 449$ J/kgK

$c_w = 4190$ J/kgK

$L_v = 22.6 \times 10^5$ J/kgK

$m_b = 0.512$ Kg

-2

$m_w = 0.06$ kg $\quad \frac{3}{4}$ boiled away

-1

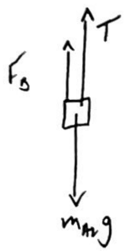
FIG. EX15.18

1: $V_{Al} = 110\,cm^3 \times \left(\frac{1m}{100cm}\right)^3 = 1.1\times10^{-4}\,m^3$

$\rho_{Al} = 2{,}700\,kg/m^3$

$\rho_{ETH} = 790\,kg/m^3$

a)



$\vec{F}_{net,y} = m\vec{a}_y$

so

$T + F_B - m_{Al}g = 0$

$T = m_{Al}g - F_B$

now $F_B = \rho_{ETH} V_{ETH}\, g = \rho_{ETH} V_{Al}\, g = m_{ETH}\, g$

NOW

$m_{Al} = \rho_{Al} V_{Al} = \left(2{,}700\,\frac{kg}{m^3}\right)\left(1.1\times10^{-4}\,m^3\right) = 0.297\,kg$

$m_{ETH} = \rho_{ETH} V_{Al} = \left(790\,\frac{kg}{m^3}\right)\left(1.1\times10^{-4}\,m^3\right) = 0.0869\,kg$

$T = (m_{Al} - m_{ETH})g = (0.297\,kg - 0.0869\,kg)(9.8\,m/s^2)$

$\boxed{T = 2.1\,N}$

2. $n = 0.10\,mol$ of ARGON

$V_i = 55cm^3 \times \left(\frac{1m}{100cm}\right)^3 = 5.5\times10^{-5}\,m^3$ now $pV = nRT$

$T_i = 296K$, $V_f = 220cm^3 = 2.2\times10^{-4}\,m^3$

INITIAL

a) $p_i = \frac{nRT_i}{V_i} = \frac{(0.10mol)(8.31J/mol\,K)(296K)}{(5.5\times10^{-5}m^3)} = 4.47\times10^{6}Pa$

ISOTHERMAL EXPANSION $T_f = T_i$ so

$$p_iV_i = p_fV_f \Rightarrow p_f = p_i\frac{V_i}{V_f} = \frac{(4.47\times10^{6}Pa)(5.5\times10^{-5}m^3)}{(2.2\times10^{-4}m^3)}$$

$$\left[p_f = 1.11\times10^{6}Pa\right]$$

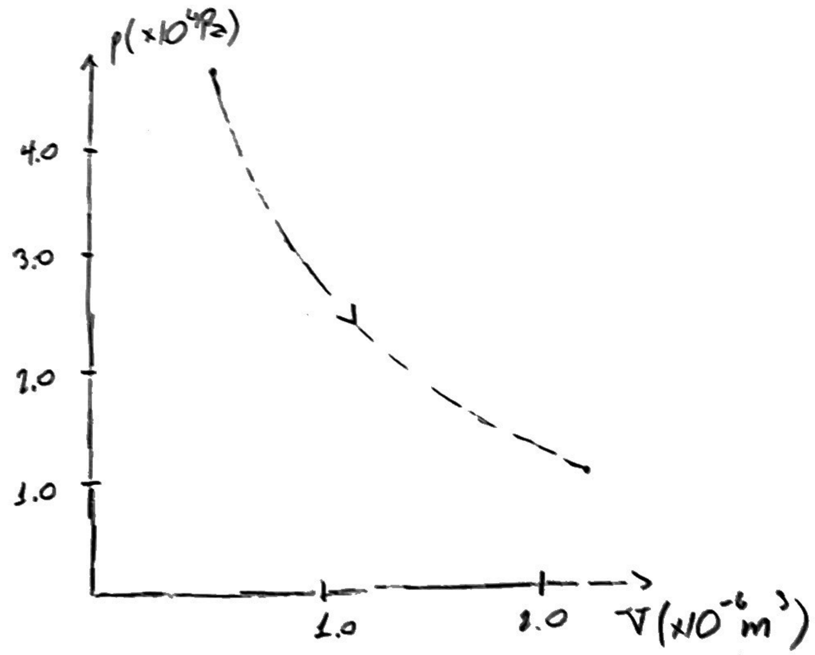


FIGURE EX 17.63

3.

$p_1 = 3.03 \times 10^5 Pa \quad = p_2$

$= 100 cm^3 \times \left(\frac{1m}{100cm}\right)^3 = 1.0 \times 10^{-4} m^3$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3}$$

$V_2 = 300cm^3 = 3.0 \times 10^{-4} m^3 = V_3 \quad = 3V_1$

$T_1 = T_3 = 100°C = 373K$

COMPARING STATES 1 : 2, ISOBARIC PROCESS SO $p_1 = p_2$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \therefore \quad T_2 = T_1 \frac{V_2}{V_1} = 373K\left(\frac{3V_1}{V_1}\right) = 1{,}120K$$

) $T_1 = T_3 = 373K$

$T_2 = 1{,}120K$

) FOR PROCESS $1 \to 2$, ISOBARIC PROCESS...

$\Delta E_{th} = n C_V \Delta T =$ NOW $PV = nRT$ SO $n = \frac{pV}{RT} = \frac{(3.03 \times 10^5 Pa)(1.0 \times 10^{-4} m^3)}{(8.31 J/mol \cdot K)(373K)}$

$= (9.78 \times 10^{-3} mol)(12.5 \frac{J}{mol \cdot K})(1{,}120K - 373K)$ $= 9.78 \times 10^{-3} mol$

$[\Delta E_{th} = 91J]$

$W = -p\Delta V = -(3.03 \times 10^5 Pa)(3.0 \times 10^{-4} m^3 - 1.0 \times 10^{-4} m^3) = -61J$

$[W = -61J]$

ALSO $\Delta E_{th} = Q + W$ SO $Q = \Delta E_{th} - W = 91J - (-61J) = 152J$

$[Q = 150J]$

) FOR PROCESS $2 \to 3$, ISOCHORIC PROCESS $\therefore W = 0J$

$\Delta E_{th} = n C_V \Delta T = (9.78 \times 10^{-3} mol)(12.5 J/mol \cdot K)(373K - 1120K) = -91J$

SO $\Delta E_{th} = W + Q = Q$

SO

$[\Delta E_{th} = Q = -91J]$: $[W = 0J]$

4. $m_{Fe} = 0.512\,kg$

$T_{i,Fe} = 790°C = 1{,}063\,K$

$T_{f,Fe} = T_{f,H_2O} = 100°C = 373\,K$

$m_{H_2O} = 0.210\,kg$

$V_{H_2O} = 210\times10^{-3}\,L \times \frac{1\,m^3}{1000\,L} = 2.1\times10^{-4}\,m^3$

Now

$T_{i,H_2O} = 22°C = 295\,K$

$m = \rho_{H_2O} V_{H_2O} = (1{,}000\,kg/m^3)(2.1\times10^{-4}\,m^3) = 0.210\,kg$

$$Q_{Fe} + Q_{H_2O} = 0$$

$$m_{Fe} C_{Fe}(373K - 1063K) + m_{H_2O} C_{H_2O}(373K - 295K) + m^*_{H_2O} L_{v,H_2O} = 0$$

so

$$m^*_{H_2O} = \frac{-m_{Fe} C_{Fe}(-690K) - m_{H_2O} C_{H_2O}(78K)}{L_{v,H_2O}}$$

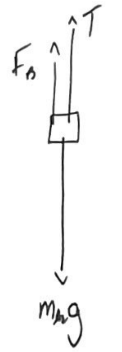
$$= \frac{-(0.512\,kg)(449\,J/kg\,K)(-690K) - (0.210\,kg)(4{,}190\,J/kg\cdot K)(78K)}{(22.6\times10^{5}\,J/kg)}$$

$$= \frac{1{,}586\times10^{5}\,J - 6.86\times10^{4}\,J}{22.6\times10^{5}\,J/kg} = 3.98\times10^{-2}\,kg = 39.8\,g$$

SO THE FRACTION OF THE H_2O THAT BOILS OFF IS..

$$\frac{m^*_{H_2O}}{m_{H_2O}} = \frac{39.8\,g}{210\,g} = 0.19$$

1a



+6

$T = m_{Al}g - F_B$ +6

$F_B = \rho_{eth} V_{eth} g$ +2

$V_{Al} = V_E$ +2

$T = 2.1 N$ +4

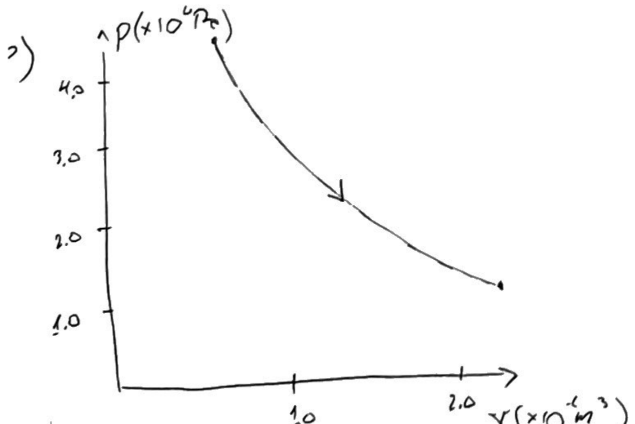
$p_i = \dfrac{nRT_i}{V_i}$ +3

$p_i = 4.47 \times 10^6 Pa$ +3

$p_f = p_i \dfrac{V_i}{V_f}$ +3

$p_f = 1.1 \times 10^6 Pa$ +3

c)



LABELS +1

SCALE +1

ARROW +1

SHAPE +5

3a) $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$ +3

$T_2 = 1{,}120 K$ +2

b) $n = \dfrac{pV}{RT}$ +2

$n = 9.78 \times 10^{-3} mol$ +1

1→2

$\Delta E_{th} = nC_V \Delta T$ +1	or	$Q = nC_P \Delta T$
$\Delta E_{th} = 91 J$ +1		$Q = 150 J$
$W = -p\Delta V$ +1		$W = -p\Delta V$
$W = -61 J$ +1		$W = -61 J$
$Q = \Delta E_{th} - W$ +1		$\Delta E_{th} = Q + W$
$Q = 150 J$ +1		$\Delta E_{th} = 89 J$

2→3

$W = 0$ +2

$\Delta E_{th} = nC_V \Delta T$ +1

$\Delta E_{th} = -91 J$ +1

$Q = \Delta E_{th}$ +1

$Q = -91 J$ +1

4. $m_{H_2O} = \rho_{H_2O} V_{H_2O}$ +2

$m_{H_2O} = 0.210 kg$ +1

a) $m_{Fe} c_{Fe} \underbrace{(373K - 1063K)}_{+1} + m_{H_2O} c_{H_2O} \underbrace{(373K - 295K)}_{+1} + \underset{\text{Diff. } +1}{\overset{+1}{m^*_{H_2O}}} \underset{+1}{L_{v,H_2O}} = 0$

3 CORRECT TERMS +9

$m^*_{H_2O} = 3.98 \times 10^{-2} kg$ +2

$\dfrac{m^*_{H_2O}}{m} = 0.19$ +1